Naval Education and Training Command

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Training Manual (TRAMAN) and Nonresident Training Course (NRTC)

Fire Controlman

Volume 2—Fire-Control Radar Fundamentals

Only one answer sheet is included in the NRTC. Reproduce the required number of sheets you need or get answer sheets from your ESO or designated officer.

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Although the words *he*, *him*, and *his* are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading this text.

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Naval Education and Training Professional Development and Technology Center

FIRE CONTROLMAN
VOLUME 2

FIRE-CONTROL
RADAR FUNDAMENTALS

NAVEDTRA 12404

1997 Edition Prepared by
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PREFACE

This training manual (TRAMAN), *Fire Controlman*, Volume 2, *Fire-Control Radar Fundamentals*, NAVEDTRA 12404, is the second volume in a new six-volume series for the Fire Controlman rating. The TRAMAN and its associated nonresident training course (NRTC) form a self-study package designed to help you gain the knowledge required for responsibilities in the area of radar fundamentals as they relate to your duties as a Fire Controlman technician.

This TRAMAN provides subject matter that relates directly to the occupational standards for Fire Controlnan. Its NRTC provides the method to satisfy the requirements for completing the TRAMAN and contains supporting questions to lead you through the manual. You may find it beneficial to browse through the entire training package before you begin serious study.

Your suggestions and comments on this self-study package are invited. You may send your recommendations to the Commanding Officer, Naval Education and Training Professional Development and Technology Center (Code N311), 6490 Saufley Field Road, Pensacola, Florida 32509-5237.

This TRAMAN and its NRTC were prepared by the Naval Education and Training Professional Development and Technology Center, Pensacola, Florida, for the Chief of Naval Education and Training.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations, we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CHAPTER 1

INTRODUCTION TO BASIC RADAR SYSTEMS

LEARNING OBJECTIVES

Upon completing this chapter, you should be able to do the following:

1. Describe basic radar concepts.

2. Identify equipment requirements for basic radar systems.

INTRODUCTION

This chapter discusses radar principles and basic radar systems that you may encounter as a Fire Controlman at your command. The Navy Electricity and Electronics Training Series (NEETS), especially Module 18, *Radar Principles*, NAVEDTRA 172-18-00-84, provides information that is basic to your understanding of this chapter. You should, therefore, refer to NEETS Module 18 and to *Electronics Installation and Maintenance Book, Radar*, NAVSEA SE000-00-EIM-020, on a regular basis to ensure that you have a complete understanding of this subject matter.

As a Fire Controlman Second Class, and a possible work-center supervisor, you must understand the basic radar principles and safety requirements for radar maintenance. However, your first assignment may not afford you exposure to radar systems.

This chapter is not designed to teach you every radar system the Navy uses, but simply to familiarize you with the radars and their general characteristics. Because there are so many different models of radar equipment, this chapter describes only the radars and radar accessories that are used in the fleet today. Older radar systems that are currently installed in the fleet, but which are scheduled for replacement, are not discussed.

BASIC RADAR CONCEPTS

The term *radar* is an acronym made up of the words *radio, detection, and ranging.* It refers to electronic equipment that detects the presence, direction, height, and distance of objects by using reflected electromagnetic energy. The frequency of electromagnetic energy used for radar is unaffected by darkness and weather. This permits radar systems to determine the position of ships, planes, and landmasses that are invisible to the naked eye because of distance, darkness, or weather.

Radar systems provide only a limited field of view and require reference coordinate systems to define the positions of detected objects. Radar surface angular measurements are normally made in a clockwise direction from true north, as shown in figure 1-1, or from the heading line of a ship or aircraft. The actual radar location is the center of this coordinate system.

Table 1-1 defines the basic terms in figure 1-1 that you need to know to understand the coordinate system.

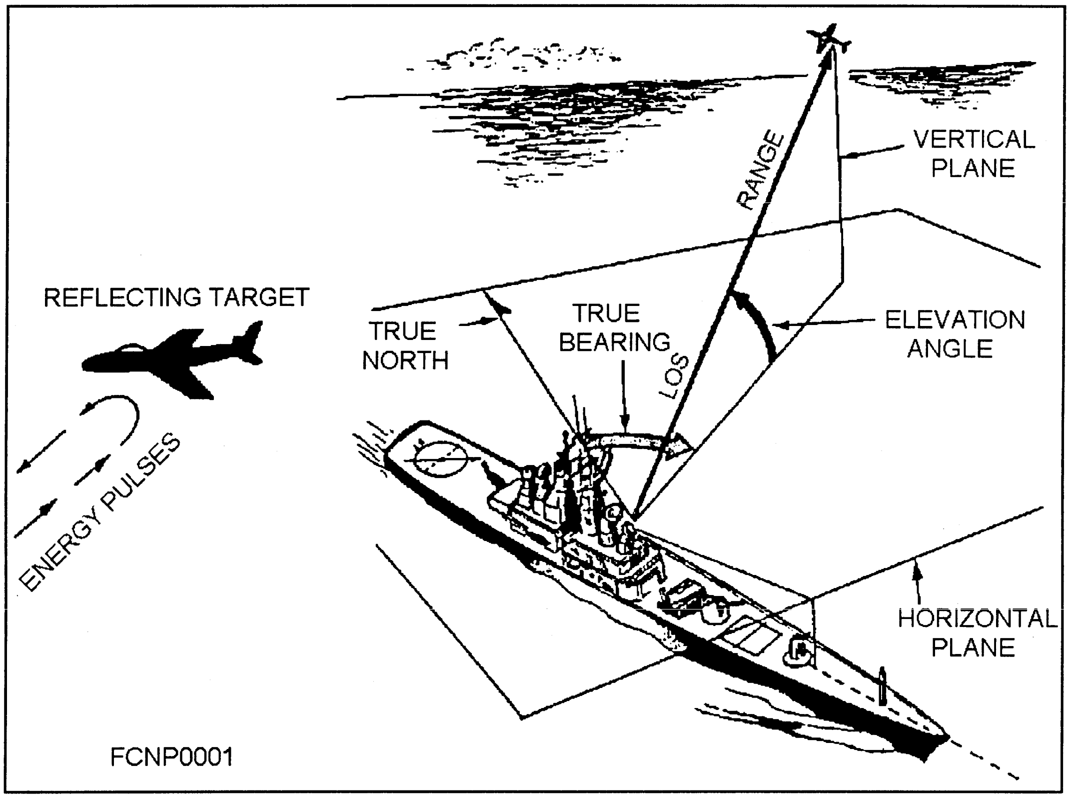

Figure 1-1.—Radar reference coordinates.

Table 1-1.—Radar Reference Coordinate Terms

Term	Definition
Energy pulses	The pulses that are sent out by the radar and are received back from the target.
Reflecting target	The air or surface contact that provides an echo.
True north	The direction of the north geographical pole.
True bearing/azimuth	The angle measured clockwise from true north in the horizontal plane.
Light-of-sight range	The length of the line from the radar set directly to the object.
Vertical plane	All angles in the up direction, measured in a secondary imaginary plane.
Elevation angle	The angle between the horizontal plane and the line of sight.
Horizontal plane	The surface of the Earth, represented by an imaginary flat plane which is tangent (or parallel) to the Earth's surface at that location.

RANGE/BEARING/ALTITUDE

Radar systems use the reference coordinates to provide early detection of surface and air targets, resulting in extremely accurate information on distance, direction, height, and speed of the targets. The visual radar data required to determine a target's position and to track the target is usually displayed on a specially designed cathode-ray tube (CRT) installed in a unit known as a plan position indicator (PPI).

Some types of radar are also used to guide missiles to targets and to direct the firing of gun systems; other types of radar provide long-distance surveillance and navigation information.

Range and bearing (and in the case of aircraft, altitude) are necessary to determine target movement. It is very important that you understand the limitations of your radar system in the areas of range, bearing, and altitude.

Range

The radar measurement of range (or distance) is possible due to the properties of radiated electromagnetic energy. This energy normally travels through space in a straight line, at a constant speed, and varies only slightly due to atmospheric and weather conditions.

MINIMUM RANGE.— Radar duplexers alternately switch the antenna between the transmitter and the receiver so that one antenna can be used for both functions. The timing of this switching is critical to the operation of the radar and directly affects the minimum range of the radar system. A reflected pulse will not be received during the transmit pulse and subsequent receiver recovery time. Therefore, any reflected pulses from close targets that return before the receiver is connected to the antenna will be undetected.

MAXIMUM RANGE.— The maximum range of a pulse-radar system depends on carrier frequency, peak power of the transmitted pulse, pulse-repetition frequency (PRF) or, and receiver sensitivity pulse-repetition rate (PRR).

The peak power of the pulse determines what maximum range the pulse can travel to a target and still return a usable echo. A usable echo is the smallest signal detectable by a receiver that can be processed and presented on an indicator.

The PRR will determine the frequency that the indicator is reset to the zero range. With the leading edge of each transmitted pulse, the indicator time base used to measure the returned echoes is reset, and a new sweep appears on the screen. If the transmitted pulse is shorter than the time required for an echo to return, that target will be indicated at a false range in a different sweep. For example, the interval between pulses is 610 µsec with a repetition rate of 1,640 pulses per second. Within this time, the radar pulse can go out and come back a distance equal to 610 µsec x 164 yards per µsec, or 100,000 yards, which becomes the scope's sweep limit. Echoes from targets beyond this distance appear at a false range. Whether an echo is a true target or a false target can be determined by simply changing the PRR.

RANGE ACCURACY.— The shape and width of the radio-frequency (RF) pulse influences minimum range, range accuracy, and maximum range. The ideal pulse shape is a square wave that has vertical leading and trailing edges. A sloping trailing edge lengthens the pulsewidth. A sloping leading edge provides no definite point from which to measure elapsed time on the indicator time base.

Other factors affecting range are the antenna height, the antenna beamwidth, and the antenna rotation rate. A higher antenna will create a longer radar horizon, which allows a greater range of detection. Likewise, a more-concentrated beam has a greater range capability, since it provides higher energy density per unit area. Also, because the energy beam strikes each target more times, a slower antenna rotation provides stronger echo returns and a greater detection range for the radar.

Given the range information, the operator knows the distance to an object, but information on bearing is still required to determine in which direction from the ship the target lies.

Bearing

Radar bearing is determined by the echo signal strength as the radiated energy lobe moves past the target. Since search radar antennas move continuously, the point of maximum echo return is determined either by the detection circuitry as the beam passes the target or visually by the operator. Weapons control and guidance radar systems are positioned to the point of maximum signal return and are maintained at that position either manually or by automatic tracking circuits.

TRUE BEARING.— The angle between true north and a line pointed directly at a target is called the *true bearing* (referenced to true north) of a radar target. This angle is measured in the horizontal plane and in a clockwise direction from true north.

RELATIVE BEARING.— The angle between the centerline of your ship or aircraft and a line pointed directly at a target is called the *relative bearing* of the radar target. This angle is measured in a clockwise direction from the centerline. Most surface-search radars provide only range and bearing information. If the operator were to have a need to direct air traffic or to track incoming missiles, the radar would also have to provide altitude. Both true and relative bearing angles are illustrated in figure 1-2.

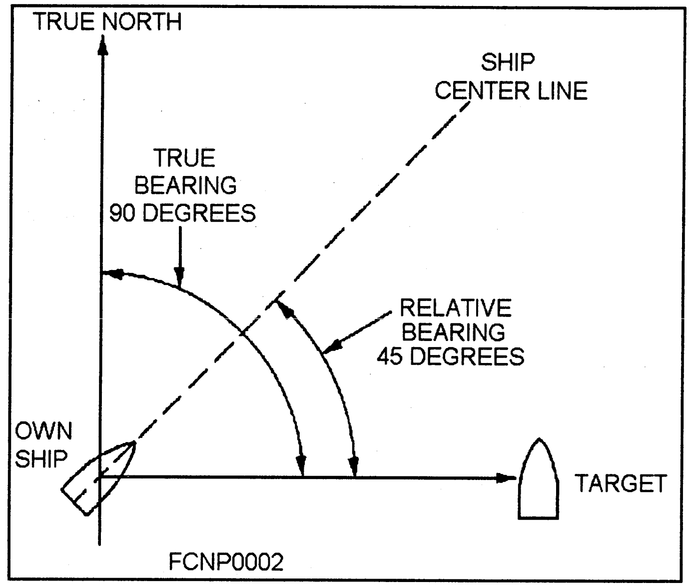

Figure 1-2.—True and relative bearings.

Altitude

An operator can determine the altitude of a target by adjusting a movable height line on a height indicator to the point where the line bisects the center of the target. The altitude is then displayed by an altitude dial or a digital readout. A search radar system that detects altitude as well as range and bearing is a three-dimensional (3-D) radar.

Altitude or height-finding radars use a very narrow beam in the vertical plane. This beam is scanned in elevation, either mechanically or electronically, to pinpoint targets. Tracking and weapons-control radar systems commonly use mechanical elevation scanning techniques that require mechanically moving the antenna or the radiation source.

Most air-search radars use electronic elevation scanning techniques. Some older air-search radar systems use a mechanical elevation scanning device; however, these are being replaced by electronically scanning radar systems.

RADAR DETECTING METHODS

Radar systems are normally divided into operational categories based on energy transmission methods. Although the pulse method is the most common method of transmitting radar energy, two other methods are sometimes used in special applications. These are the continuous-wave method and the frequency-modulation method.

Continuous Wave

The continuous-wave (CW) method uses the Doppler effect to detect the presence and speed of an object moving toward or away from the radar. The system is unable to determine the range of the object or to differentiate between objects that lie in the same direction and are traveling at the same speed. It is usually used by fire-control systems to track fast-moving targets at close range.

Frequency Modulation

In the frequency-modulation (FM) method, energy is transmitted as RF waves that continuously vary, increasing and decreasing, from a fixed-reference frequency. Measuring the difference between the frequency of the returned signal and the frequency of the radiated signal gives an indication of range. This system works well with stationary or slowly moving targets, but it is not satisfactory for locating fast-moving objects. It is used in aircraft altimeters that give a continuous reading of how high the aircraft is above the Earth.

Pulse Modulation

In the pulse-modulation method, depending on the type of radar, energy is transmitted in pulses that vary from less than 1μ to 200μ. The time interval between transmission and reception is computed and converted into a visual indication of range in miles or yards. Pulse-radar systems can also be modified to use the Doppler effect to detect a moving object. The Navy uses pulse-modulation radars to a great extent.

FACTORS AFFECTING RADAR PERFORMANCE

Radar accuracy is a measure of the ability of a radar system to determine the correct range, bearing, and, in some cases, altitude of an object. The degree of accuracy is primarily determined by the resolution of the radar system and atmospheric conditions.

Range Resolution

Range resolution is the ability of a radar to resolve between two targets on the same bearing, but at slightly different ranges. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of the targets, and the efficiency of the receiver and the indicator.

Bearing Resolution

Bearing, or azimuth, resolution is the ability of a radar system to separate objects at the same range, but at slightly different bearings. The degree of bearing resolution depends on radar beamwidth and the range of the targets. The physical size and shape of the antenna determines beamwidth. Two targets at the same range must be separated by at least one beamwidth to be distinguished as two objects.

Some external factors that affect radar performance are operator skill; size, composition, angle, and altitude of the target; possible electronic attack (EA) activity; readiness of equipment (completed planned maintenance system requirements); and weather conditions.

Atmospheric Conditions

Several conditions within the atmosphere can have an adverse effect on radar performance. A few of these are temperature inversion, moisture lapse, water droplets, and dust particles.

Either temperature inversion or moisture lapse, alone or in combination, can cause a large change in the refraction index of the lowest few-hundred feet of the atmosphere. The result is a greater bending of the radar waves passing through the abnormal condition. The increased bending in such a situation is referred to as *ducting,* and may greatly affect radar performance. The radar horizon may be extended or reduced, depending on the direction in which the radar waves are bent. The effect of ducting is illustrated in figure 1-3.

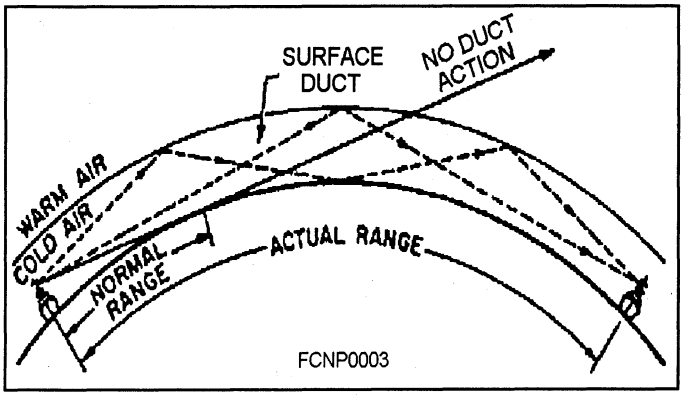

Figure 1-3.—Ducting effect on the radar wave.

Water droplets and dust particles diffuse radar energy through absorption, reflection, and scattering. This leaves less energy to strike the target, so the return echo is smaller. The overall effect is a reduction in usable range. Usable range varies widely with such weather conditions. The higher the frequency of the radar system, the more it is affected by weather conditions, such as rain or clouds.

Since all radar systems perform the same basic functions of detection, they all have the same basic equipment requirements.

BASIC RADAR SYSTEMS

Radar systems, like other complex electronics systems, are composed of several major subsystems and many individual circuits. Although modern radar systems are quite complicated, you can easily understand their operation by using a basic block diagram of a pulse-radar system.

FUNDAMENTAL RADAR SYSTEM

Since most radars used today are some variation of the pulse-radar system, this section discusses those used in a pulse radar. All other types of radars use some variation of these units. Refer to the block diagram in figure 1-4.

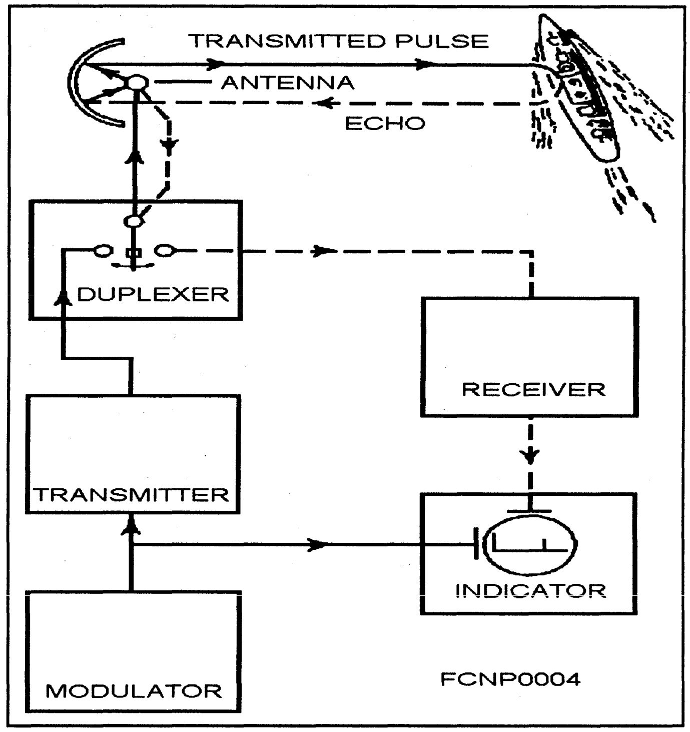

Figure 1-4.—Block diagram of a fundamental radar system.

Modulator

You can see on the block diagram that the heart of the radar system is the modulator. It generates all the necessary timing pulses (triggers) for use in the radar and its associated systems. Its function is to ensure that all subsystems of the radar system operate in a definite time relationship with one another and that the intervals between pulses, as well as the pulses themselves, are of the proper length.

Transmitter

The transmitter generates powerful pulses of electromagnetic energy at precise intervals. The required power is obtained by using a high-power microwave oscillator (such as a magnetron) or a microwave amplifier (such as a klystron) that is supplied by a low-power RF source.

For further information on the construction and operation of microwave component, review NEETS Module 11, *Microwave Principles,* NAVEDTRA 172-11-00-87.

Duplexer

The duplexer is essentially an electronic switch that permits a radar system to use a single antenna to both transmit and receive. The duplexer must connect the antenna to the transmitter and disconnect the antenna from the receiver for the duration of the transmitted pulse. The switching time is called *receiver recovery time,* and must be very fast if close-in targets are to be detected.

Antenna System

The antenna system routes the pulse from the transmitter, radiates it in a directional beam, picks up the returning echo, and passes it to the receiver with a minimum of loss. The antenna system includes the antenna, transmission lines, and waveguide from the transmitter to the antenna, and transmission lines and waveguide from the antenna to the receiver.

Receiver

The receiver accepts the weak RF echoes from the antenna system and routes them to the indicator as discernible video signals. Because the radar frequencies are very high and difficult to amplify, a superheterodyne receiver is used to convert the echoes to a lower frequency, called the intermediate frequency (IF), which is easier to amplify.

TYPES OF RADAR SYSTEMS

Because of different design parameters, no single radar set can perform all the many radar functions required for military use. The large number of radar systems used by the military has forced the development of a joint-services classification system for accurate identification of radars. Radar systems are usually classified according to their specific function and installation vehicle. The joint-service standardized classification system divides these broad categories for more precise identification.

Since no single radar system can fulfill all the requirements of modern warfare, most modern warships, aircraft, and shore installations have several radar sets, each performing a specific function. A shipboard radar installation may include surface-search and navigation radars, a 3-D radar, an air-search radar, and various fire-control radars.

Table 1-2 is a listing of equipment identification indicators. You can use this table and the radar nomenclature to identify the parameters of a particular radar set.

Table 1-2.—Table of Equipment Indicators

Installation (1st letter)	Type of Equipment (2nd letter)	Purpose (3rd letter)	Miscellaneous Identification
A Piloted aircraft	A Invisible light, heat radiation	B Bombing	X, Y, Z Changes in voltage, phase, or frequency
B Underwater mobile, submarine	C Carrier	C Communications (receiving and transmitting)	T Training
D Pilotless carrier	D Radiac	D Direction finder reconnaissance and/or surveillance	(V) Variable grouping
F Fixed ground	G Telegraph or teletype	E Ejection and/or release	
G General ground use	I Interphone and public address	G Fire control or searchlight directing	
K Amphibious	J Electromechanical or inertial wire covered	H Recording and/or reproducing (graphic meteorological and sound)	
M Ground, mobile	K Telemetering	K Computing	
P Portable	L Countermeasures	M Maintenance and/or test assemblies including tools	
S Water	M Meteorological	N Navigational aids, including altimeters, beacons, depth sounding, approach and landing	
T Ground, transportable	N Sound in air	Q Special or combination of purposes	
U General utility	P Radar	R Receiving, passive detecting	
V Ground, vehicular	Q Sonar and underwater sound	S Detecting and/or range and bearing, search	
W Water surface and underwater combination	R Radio	T Transmitting	
Z Piloted and pilotless airborne vehicle combination	S Special types, magnetic, etc., or combinations of types	W Automatic flight or remote control	
	T Telephone (wire)	X Identification and recognition	
	V Visual and visible light	Y Surveillance (search detect and multiple target tracking) and control (both fire control and air control)	
	W Armament (peculiar to armament, not otherwise covered)		
	X Facsimile or television		
	Y Data processing		

Air-Search Radar

The primary function of an air-search radar is to maintain a 3600 surveillance from the surface to high altitudes and to detect and determine ranges and bearings of aircraft targets over relatively large areas.

The following are some applications of an air-search radar:

- Gives early warning of approaching enemy aircraft and missiles, providing the direction from which an attack could come to allow time to bring antiaircraft defenses to the proper degree of readiness and to launch fighters if an air attack is imminent.
- Observes constantly the movement of enemy aircraft, once detected, to guide combat air patrol (CAP) aircraft to a position suitable for an intercept.
- Provides security against attacks at night and during times of poor visibility.
- Provides information used for aircraft control during operations that require a specific geographic track (such as an antisubmarine barrier or a search and rescue pattern).

Together, surface- and air-search radars provide a good early-warning system. However, the ship must be able to determine altitude to effectively intercept any air target. This requires still another type of radar.

3-D Radar

The primary function of a 3-D radar is to compute accurate ranges, bearings, and altitudes of targets detected by an air-search radar. This information is used to direct fighter aircraft during interception of air targets.

The 3-D radar is different from the air-search radar in that it has a higher transmitting frequency, higher output power, and a much narrower vertical beamwidth. In addition, it requires a stabilized antenna for altitude accuracy.

The following are some applications of a 3-D radar:

- Obtains range, bearing, and altitude data on enemy aircraft and missiles to assist in the guidance of CAP aircraft.
- Provides precise range, bearing, and height information for fast and accurate initial positioning of fire-control tracking radars.
- Detects low-flying aircraft.
- Determines range to distant landmasses.
- Tracks aircraft over land.
- Detects certain weather phenomena.
- Tracks weather balloons.

The modern warship has several radars. Each radar is designed to fulfill a particular need, but may also be capable of performing other functions. For example, most 3-D radars can be used as secondary air-search radars; in emergencies, fire-control radars have served as surface-search radars. A 3-D air-search radar is shown in figure 1-5.

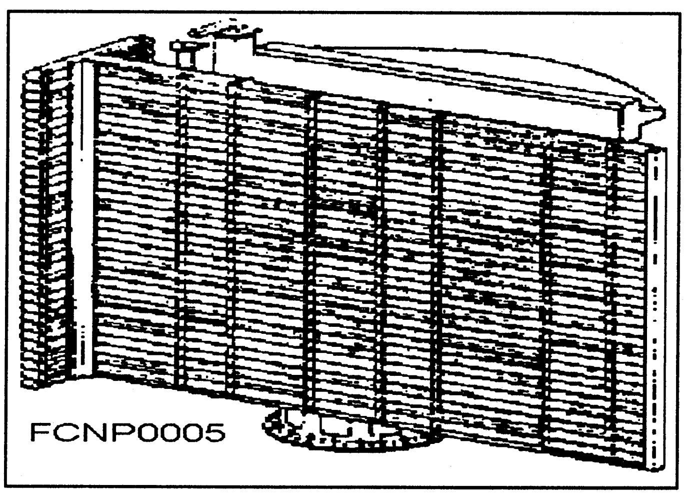

Figure 1-5.—3-D air-search radar.

FIRE-CONTROL RADAR

Radar that provides continuous positional data is called a *tracking radar.* Most tracking radar systems used by the military are also called *fire-control radars,* the two names being interchangeable. A fire-control tracking radar system usually produces a very narrow, circular beam.

The three sequential phases of radar operation (designation, acquisition, and track) are often referred to as *modes* and are common to the target-processing sequence of most fire-control radars.

- **Designation Phase:** The fire-control radar must be directed to the general location of the target due to the radar's narrow beamwidth.

- **Acquisition Phase:** The fire-control radar switches to the acquisition phase of operation once the radar is in the general vicinity of the target. During this phase, the radar system searches in the designated area in a predetermined search pattern until the target is located or redesignated.

- **Track Phase:** The fire-control radar enters into the track phase when the target is located. The radar system locks onto the target during this phase.

Typical fire-control radar characteristics include high pulse-repetition frequency, a very narrow pulse-width, and a very narrow beamwidth. A typical fire-control antenna is shown in figure 1-6.

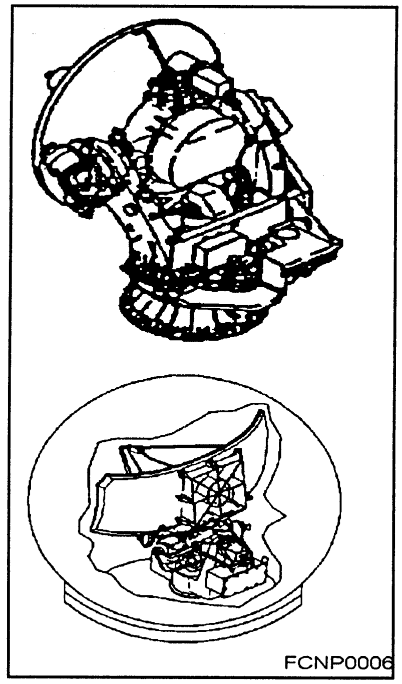

Figure 1-6.—Typical fire-control antenna.

RECOMMENDED READING LIST

NOTE: Although the following references were current when this TRAMAN was published, their continued currency cannot be assured. Therefore, you need to ensure that you are studying the latest revision.

Microwave Principles, Module 11, Navy Electricity and Electronics Training Series, NAVEDTRA 172-11-00-87, Navy Education and Training Program Management Support Activity, Pensacola, FL, 1987.

Radar, NAVSEA SE000-00-EIM-020, *Electronics Installation and Maintenance Book* (EIMB), Naval Sea Systems Command, Washington, DC, 1974.

Radar Principles, Module 18, Navy Electricity and Electronics Training Series, NAVEDTRA 172-18-00-84, Naval Education and Training Program Development Center, Pensacola, FL, 1984.*

* Effective 1 September 1986, the Naval Education and Training Program Development Center became the Naval Education and Training Program Management Support Activity.